Reunion Island energy autonomy objective by 2030

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1. Introduction

Since 2000 the overseas French Region of La Réunion (or Reunion Island), located between Mauritius and Madagascar in the Indian Ocean, has adopted a strategy of energy autonomy based on greater energy efficiency and renewable energy alternatives. The law "Grenelle 1" n° 2009-967 issued from the French environment roundtables called "Le Grenelle de l'environnement" states that La Réunion must achieve energy self-sufficiency by 2030.

From 1970 to 2012, the population of La Reunion has nearly doubled from 450 000 to 837 900 inhabitants. According to INSEE (2012) projections, the population is expected to reach 1 061 million in 2040. In a context of population and economic growth, between 2000 and 2012 primary energy consumption has increased by 3.1% per year and final energy consumption by 2.5 % per year. Whereas, in the 80s, all of the energy produced in Reunion Island came from renewable hydroelectricity, the island became gradually dependent on imported fossil fuels. In 2012, petrol, coal and gas represented 87.2% of primary energy consumption and renewable energies only 12,8% (OER, 2013). This strong dependence on fossil fuels leads to electrical continuity risks in case of supply disruption as well as increasing greenhouse gas emissions.

In 2012, 65% of the island’s power was generated by fossil fuel (coal and oil) power plants. However, owing to its rich natural environment, this unique European territory in the Indian Ocean has exceptional potential for renewable power generation. Reunion island is blessed with many types of renewable energy sources (RES) such as solar, wind, geothermal, sea energy (Ocean thermal energy conversion and wave energy), biomass and hydropower. Leading to energy autonomy by 2030 mean a 100% renewable electricity mix by this date. Reaching this 100% renewable electricity mix will involve many structural changes in electricity production. The production of electricity from hydropower is the main renewable resource of the island. It accounted for 14,6 % of the total electricity production in 2012 (133 MW of installed capacity), spread over six sites in the eastern part of the island (OER, 2013). An additional capacity of 50 MW should be deployed by 2020 (SRCAER, 2013). La Réunion 's biomass potential is important. The bagasse (sugar cane residue) resulting from sugar cane industry is entirely energy-valued in two co-firing bagasse and coal power plants. Biomass will have to be largely deployed to substitute coal in the long term, which will entail the development of more fibrous sources of sugarcane, the valorization of wood and green waste energy and the development of gasification technologies. Due to its location, solar energy is an abundant energy resource. Over the last ten years, an exponential increase of photovoltaic (PV) installations has been observed, mainly with stand-alone systems. In 2012, the installed capacity of photovoltaic solar energy was 152 MW (OER, 2013). To meet the autonomy target PV farms connected to the grid will have to be developed. The southeast and the northeast regions of the island are suitable for wind power generation. Currently two wind farms are operating with a total installed capacity of 16,5 MW in 2012 (OER, 2013). New projects of wind farms are expected. Furthermore, several other renewable technologies will have to enter the mix such as geothermal and marine energies. Research projects on marine energies are under development. Ocean thermal energy conversion (OTEC) will have to be largely deployed as well as wave energy. Geothermal energy has also a significant potential thanks to a high thermal gradient with the Piton de la Fournaise volcano. However, this potential is still under study as it is located in a protected natural zone.

The important penetration of RES in the power mix raises key issues: What will be the cost of electricity autonomy by 2030? How the large deployment of intermittent energies will affect the reliability of the electrical system? The quantification of these issues is useful to define a road map to meet the goal of electricity self-sufficiency. To address these issues we conduct a prospective analysis of the Reunion Island electricity system by 2030. The objective is to examine the changes in the current production patterns in order to move toward a 100% renewable mix by 2030. The aim of this study is to evaluate the impact of the large integration of renewable energy on the composition of the electricity mix, the total extra cost of the system as well as the reliability of the electrical system. This analyze is conducted with the bottom-up energy model TIMES-Réunion (Drouineau, 2011; Bouckaert, 2013).

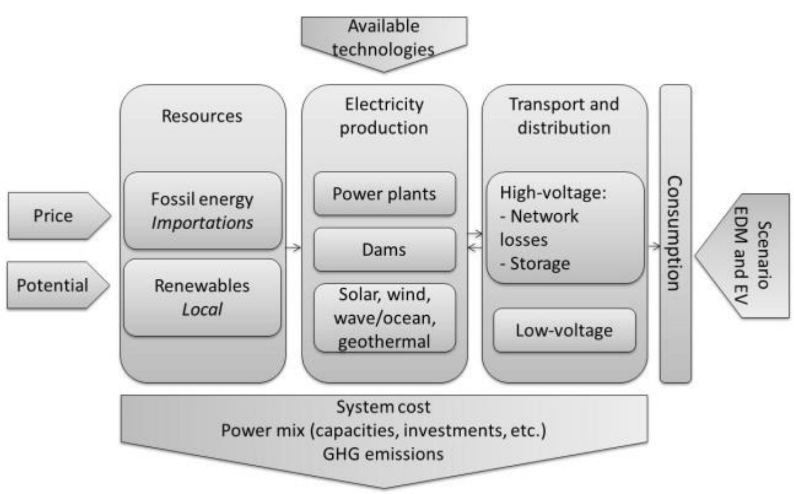
The paper is organized as follows: section 2 describes the model used for the analysis and the energy scenarios. Section 3 presents the results of the long term modeling. The final section give some concluding remarks.

2. Methodology and energy autonomy scenarios

2.1 The TIMES-Réunion model

The model used is the TIMES-Réunion model developed by the MINES ParisTech Center for Applied Mathematics (Drouineau, 2011). It is a bottom-up optimization model that offers a technology-rich representation of the Reunion island electricity system. It depicts the Reunion island electricity system with a detailed description of different primary energy sources, electricity production, transport and distribution technologies constituting the reference electricity system (figure 1).

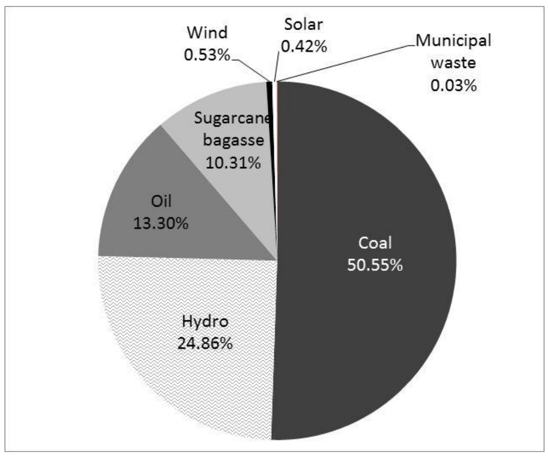
Figure 1: Reunion island Reference Energy System



The time horizon of the model range from 2008 (reference year) to 2030. This technological model is driven by an exogenous electricity demand. The model uses a linear-programming approach in which the technical optimum is computed by minimizing the discounted global system cost. It computes a total net present value of the stream of the total annual cost, discounted at 7% to the selected reference year 2008. The total annual cost includes investment and dismantling costs (capital costs) that are annualized using hurdle rates, annual fixed and variable operation and maintenance costs and costs incurred for exogenous imports and for domestic resource production.

The model is calibrated for 2008. Figure 2 shows the Reunion Island electricity mix in 2008

Figure 2: Electricity production in 2008 (source: BPPI – EDF SEI 2009)



Based on policies and projects that are conducted in Reunion Island at the moment we make assumption on the potential of renewable energies by 2030 (table 1). The data mainly come from the SRCAER (2013).

Table 1: Renewable energy potential assumptions

Energy sources	**Level in 2008**	**Potential**
Biomass	260 GWh	400 GWh
Hydropower	121 MW	268 MW
Wind	16.8 MW	50 MW
Solar PV	10 MW	160 MW
Ocean Thermal Energy Conversion (OTEC)		10 MW in 2020 100 MW in 2030
Ocean wave energy		30 MW (by 2020)
Geothermal energy		30 MW

2.2 Scenarios

BAU: A business as usual (BAU) scenario is calculated first. In this reference scenario, no specific energy policy is assumed. There is no objective of integrating renewable energy in the mix. This scenario outlines some key patterns in the evolution of the electricity system and serves as the starting point of the analysis.

100% renewable: In this scenario, there is no more fossil fuel in the electricity mix by 2030. This scenario allows us to investigate the changes induced by a strong energy policy. Thus, the BAU scenario is compared to the 100% renewable energy scenario to assess the implication of the future development of the electricity system and formulate policy recommendations.

To meet the 100% renewable target, we also explore the impact on the system of strong political choices.

Since 2000 public policies have decided to largely incentivize photovoltaic solar energy and to develop marine energies. Therefore, we consider a scenario where photovoltaic and ocean energy systems are largely developed to meet the 100% renewable target (*scenario PV-OCE*).

Another scenario consists in meeting the 100% renewable target with a large deployment of geothermal energy and biomass. Geothermal is developed through the authorization to exploit geothermal energy in a protected natural area. The sugarcane resource produced on the island is only devoted to energy. This scenario is called *Rupture*

Then, in respect with the large development of solar and wind energies, we investigate scenarios dealing with the management of intermittent energy including the exploitation rule in line with the decision of the network operator EDF that consist in limiting intermittent energy at 30% maximum on the electrical system. The scenarios are called *PV-OCE 30%* and *INT-30%*

The demand for electricity in the model is exogenous. The data come from the network operator EDF projections until 2030. In the business as usual a median scenario of demand evolution is retained whereas in all the other scenarios, we can expect that energy demand management will be put in place. Therefore the increase in demand is less important that in the BAU and we expect a deployment of electric cars by 2030 (see table 2).

Table 2: Demand scenarios

Demand Scénario	**2008**	**2010**	**2015**	**2020**	**2025**	**2030**
Median Electricity demanded (GWh)	2318	2467	2831	3187	3464	3732
Energy demand control Electricity demanded (GWh)	2318	2463	2,2	2850	2913	2957
Electric cars Electricity demanded (GWh)						1400

3. Results

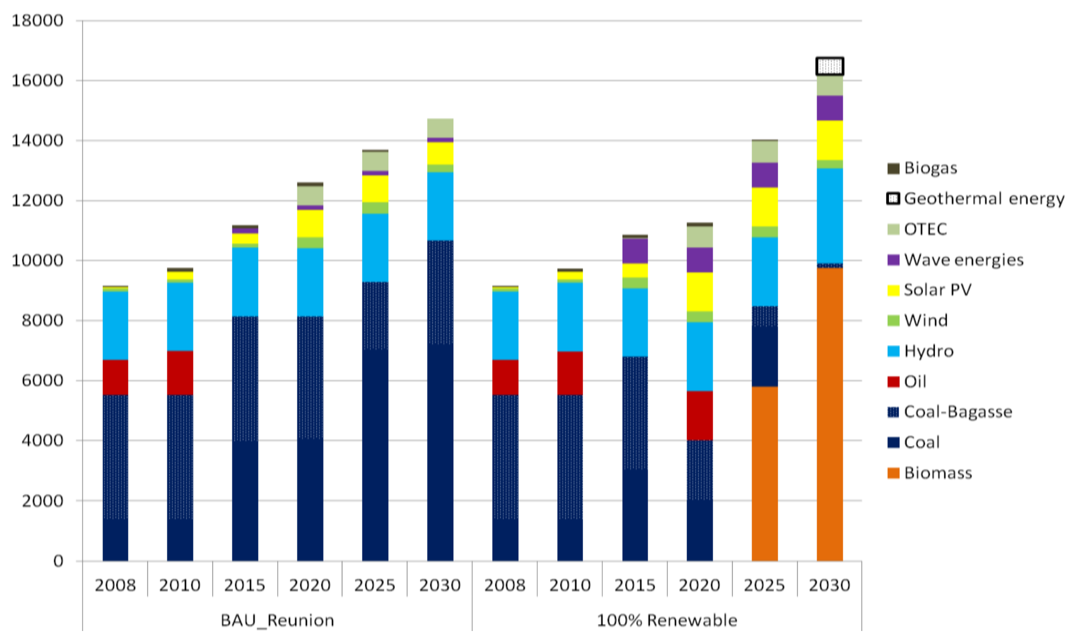
3.1 Electricity mix

We analyse the changes of the current production patterns to move toward a system capable of meeting the energy challenge.

In the *BAU scenario* (figure 3), the production of electricity gradually increase to reach 14728 TJ in 2030. This growth is based on assumptions relating to the median electricity demand scenario.
Electricity production from coal double from 2008 to 2030, indicating that without constraint to promote energy autonomy, the most economical solution for producing electricity is based on imported coal. Heavy fuel oil is absent or very poorly represented in the production mix from 2015. In 2010, the share of electricity from fuel oil is well represented (12%), because the two existing power plants are used to meet the demand. Then, it appears more profitable to invest in new coal power plants than generate electricity from heavy fuel oil.
It is interesting to note that the share of renewable energy in the production stabilizes around 35%. This value is close to the one observed in 2008 (36%).
This scenario underlines that on the one hand, the level of renewable energy in the current system is the maximum level of integration from a purely economic point of view, and on the other hand, the transition to a 100% renewable cannot be reached without an effective incentive system or regulatory constraint.

We analyse the impact of the 100% renewable target on the electricity mix (figure 3). Between 2010 and 2020, electricity production increases slowly due to lower growth assumptions in the demand management scenario. Between 2025 and 2030, the level of production catches the one in the BAU scenario with the deployment of electric vehicles. Fossil fuel consumption decreases progressively. From 2015, 50% of the electricity is produced from renewable energies.
In 2030 electricity from biomass has advantageously replaced electricity from coal and represents slightly more than 50% of electricity generation. This can be explained by the use of new varieties of sugarcane and the opportunity to develop the culture of a cane variety only dedicated to the production of energy. Massive investments in biomass gasification plants are held in 2020. Geothermal energy and marines energies are developed from 2020 to meet the target.
Unlike the BAU scenario, production of electricity from heavy fuel oil is more important in this scenario. There is a trade-off between investment in new coal-fired power plants and the use of already installed heavy fuel oil power plants in the western part of the island. It is economically more interesting, to some extent to use diesel power plants installed in 2010 and keep importing heavy fuel oil.

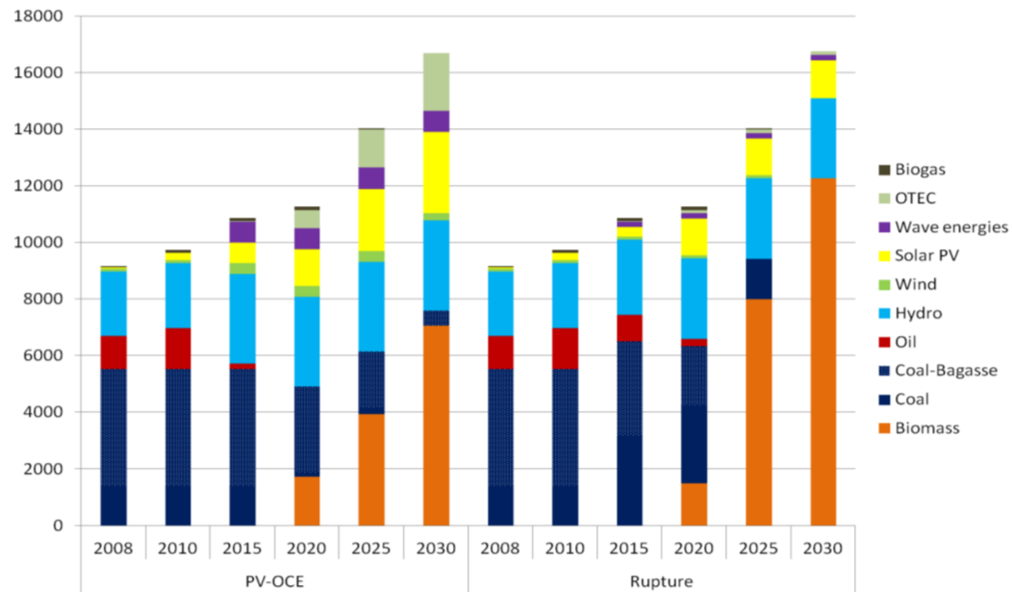
Figure 3: Electricity mix under the BAU scenario and the 100% renewable scenario (TJ)



In the PV-OCE scenario (figure 4), We can observe that production levels are the same as in the 100% renewable scenario, because we use the same demand scenario. In this scenario photovoltaic and marine energies have been greatly encouraged. Therefore, in 2030, these two energies represent about 30% of the electricity production. Hydroelectricity increased slightly between 2010 and 2015 and then remains constant over the study period. In this scenario the wind turbines are not replaced and they almost disappear in 2030.

In the rupture scenario (figure 4), there is a strong development of the electricity generated from biomass. The production of sugar cane is being phased out in favour of cane energy. Electricity generation from bagasse rises to 12 000TJ in 2030 and represents more than 70% of electricity production. In addition, the geothermal option is not developed, while the site in the protected natural zone is possible in this scenario.

Figure 4: Electricity mix under PV-OCE and rupture scenarios (TJ)

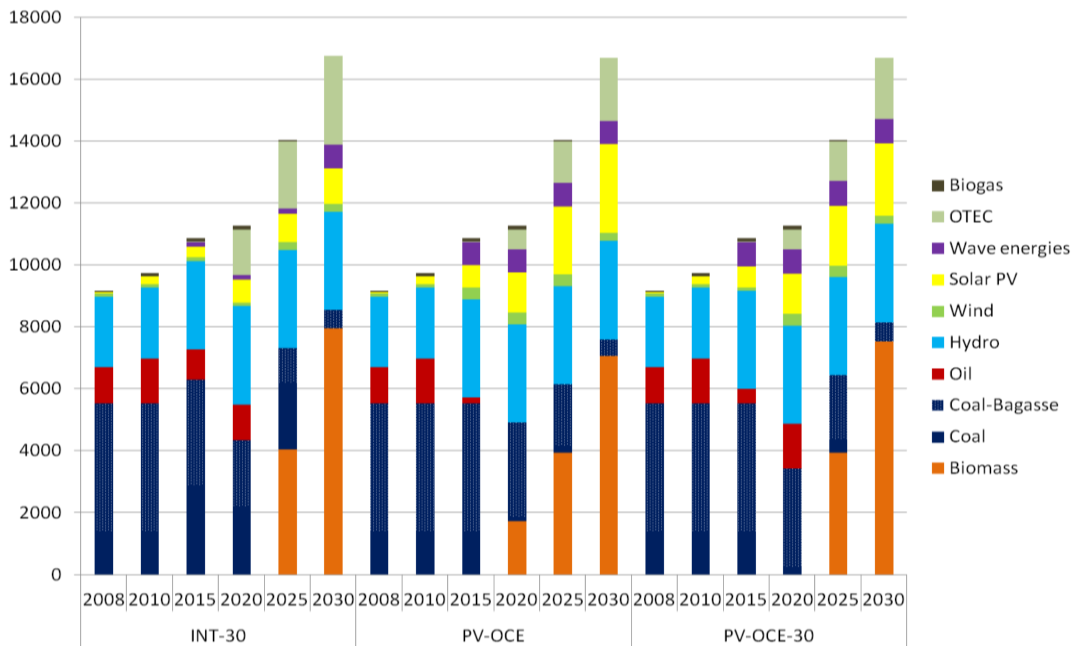


3.2 Intermittence management

In the *PV-OCE 30%* (figure 5) potential of renewable energy and capacity of solar panels and marine energy are identical to those of scenario PV-OCE. However, we have limited to 30% the share of intermittent energy sources (solar panels, wind turbines, energy of waves, plants of the water). Compared to PV-OCE scenario, production from solar panels decrease from 17% in 2030 to 14% in this new scenario. The production deficit is filled by a slight increase in biomass use 55% against just under 52% in PV-OCE.

In *INT 30% scenario* (figure 5) we consider this operating rule and also expect a lower deployment of solar panels. Development of solar panels is fixed to 175 MW in 2020 and 260 MW in 2030. After discussion with EDF experts, this last hypothesis is more consistent with the operational constraints. Compare to PV-OCE photovoltaic share decreases from 17% to 7% . Electricity from biomass represents almost 60% of the mix and the share of geothermal energy largely increase.

Figure 5: Electricity mix under PV-OCE 30% and INT 30% (TJ)



3.3 Economic impact

We look at the extra cost of the different scenarios compare to the BAU scenario. Table 2 compares the change in total cost of the system in the various scenarios compared to the BAU. The *PV-OCE scenario* is more costly than the *100% renewable*. The least costly is the rupture scenario where biomass is largely developed. The *PV-OCE 30% scenario* is almost as costly as the *PV-OCE scenario*. There is still an expensive system development of electricity generation, because both scenarios promote a strong expansion of solar and marine energies, whose production units are expensive. In contrast, the scenario INT 30% is more competitive because the solar panels are replaced by less expensive means of production.

Table 3: Total cost of the system

	BAU	100% renewable	PV-OCE	Rupture	PV-OCE30%	INT30%
Objective function (M€) Variation (%) compare to BAU	1624,3	1867,6 15%	2018,5 24%	1753,2 8%	2055,9 27%	1812 12%

4. Discussion and conclusion

During the 1980's, the entire electricity supply came from renewable hydro-power. As the population grew and quality of life improved, coal and oil were introduced to help meet increasing demand. The strong dependence on fossil fuels for power carries reliability, economic and environmental problems. To combat the environmental hazards of continued reliance on fossil fuels, La Réunion has committed to grow sustainably: achieving energy autonomy by 2030 and integrate zero carbon practices into multiples sectors. A top priority is to reach a 100% renewable mix for power. In this context of challenges towards a transition to renewable energy, Reunion Island is a source of opportunities in terms of energy development. This study has evaluated the changes that need to be done in the power sector to meet the target in a cost effective manner. Some major technological challenges arise, particularly concerning the reliability of electricity supply and the ability of the system to withstand sudden disturbances, the intermittency and the costly construction of infrastructures. The results show that incentivizing PV solar energy and marine energies is not the most cost effective option to meet the target and effort should rather be put on biomass deployment.

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